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1 (Sem-4/FYUGP) PHY 41 MJ

2026

PHYSICS

(Major)

Paper : PHY4400104MJ

(Classical Mechanics)

Full Marks : 60

Time : 2½ hours

*The figures in the margin indicate
full marks for the questions.*

1. Answer the following questions : $1 \times 8 = 8$

(a) The number of generalised coordinates necessary to describe a diatomic molecule is

(i) 2

(ii) 3

(iii) 5

(iv) 6 (Choose the correct answer)

(b) For a system of N particles the transformation equations for the position vector of particles are

$\vec{r}_i = \vec{r}_i(q_1, q_2, \dots, q_n, t)$ where

$q_1, q_2, \dots, q_n$ are generalised coordinates. What is the expression for velocities?

(c) If for a system the generalised coordinate is angle (θ). Which of the following would represent the generalised force?

(i) Force

(ii) Energy

(iii) Torque

(iv) Angular momentum

(d) Lagrangian of a free particle of mass m moving in x -direction in $L = \frac{1}{2} m \dot{x}^2$.

What is its Hamiltonian?

(e) Hamilton canonical equations for a conservative system are

(i) $-\frac{dq_i}{dt} = \frac{\partial H}{\partial p_i}, -\frac{\partial p_i}{dt} = \frac{\partial H}{\partial q_i}$

(ii) $\frac{dp_i}{dt} = \frac{\partial H}{\partial p_i}, \frac{dp_i}{dt} = \frac{\partial H}{\partial q_i}$

(iii) $-\frac{dq_i}{dt} = \frac{\partial H}{\partial p_i}, \frac{dp_i}{dt} = \frac{\partial H}{\partial q_i}$

(iv) $\frac{dq_i}{dt} = \frac{\partial H}{\partial p_i}, -\frac{dp_i}{dt} = \frac{\partial H}{\partial q_i}$

(Choose the correct answer)

(f) If $v = 0.6c$ find the x' coordinate in S' -frame of an event in S -frame at $x = 4m, y = 0, z = 0, t = 0$.

(g) If the rest mass of a particle is zero, which of the following is correct?

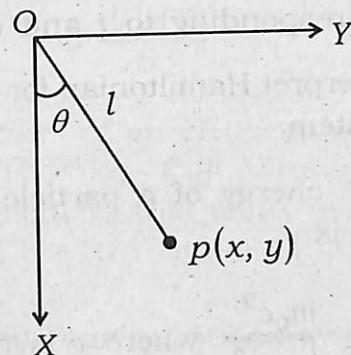
- (i) The particle is at rest for all time
- (ii) The momentum of the particle is zero
- (iii) The particle moves with velocity of light
- (iv) None of the above

(h) A particle of mass m is moving in the potential $V(x) = -\frac{1}{2}ax^2 + \frac{1}{4}bx^4$, ($a, b > 0$). Which of the following is the position of stable equilibrium?

- (i) $x = 0$
- (ii) $x = \sqrt{\frac{a}{b}}$
- (iii) $x = -\sqrt{\frac{a}{b}}$
- (iv) None of the above

2. Answer **any six** questions : $2 \times 6 = 12$

(a) A simple pendulum of length l moving in xy -plane is shown in the figure. Write down the equations of constraints in the case of the pendulum.



- (b) What are the two types of difficulties introduced by constraints in the solution of mechanical problem?
- (c) The Lagrangian of a system in terms of generalised coordinate x is given by $L = \frac{1}{2}m\dot{x}^2 - \frac{1}{2}kx^2$, where m and k are constants. Find the Euler-Lagrange equation.
- (d) The Lagrangian for a particle moving in central potential $V(r)$ is

$$L = \frac{1}{2}m(\dot{r}^2 + r^2\dot{\theta}^2) - V(r)$$

which coordinate is cyclic here and what is the corresponding momentum that is conserved?

$1+1=2$

(e) If the Lagrangian is given by

$$L = \frac{1}{2}m(\dot{r}^2 + r^2\dot{\theta}^2 + \dot{z}^2) - V(r, \theta, z)$$

Find generalised momenta corresponding to r and θ .

(f) Interpret Hamiltonian for a conservative system.

(g) The energy of a particle of rest mass m_0 is

$$E = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}} \text{ where } v \text{ is the velocity of}$$

the particle. What is the kinetic energy of the particle?

Show that for $v \ll c$, kinetic energy is

$$\text{equal to } \frac{1}{2}m_0 v^2. \quad \frac{1}{2} + 1\frac{1}{2} = 2$$

(h) A beam of particle of half life $2 \times 10^6 \text{ sec}$ travels at a speed $0.96c$. How much distance the beam travel before the flux falls to 50% of the initial flux?

(Half life is the time taken to reduce flux to half its initial value)

(i) If $V(x)$ is the potential energy of a particle moving in x -direction, write down the condition of stable equilibrium in terms of

$$\frac{dV(x)}{dx} \text{ and } \frac{d^2V(x)}{dx^2}$$

(j) The mass of an electron is $9.1 \times 10^{-31} \text{ kg}$. Calculate the energy equivalent to this mass in MeV .
[$1e = 1.6 \times 10^{-19} \text{ coulomb}$]

3. Answer **any four** questions : $5 \times 4 = 20$

(a) What are holonomic and nonholonomic constraints? A system of N particles has K number of holonomic constraints and K' number of nonholonomic constraints. What is the number of degrees of freedom for the system? How many generalised coordinates are necessary to describe it? Give an example of either holonomic constraints or nonholonomic constraints.

$$2 + 1 + 1 + 1 = 5$$

(b) Use Euler-Lagrange equation to find the equation of motion of a compound pendulum in a vertical plane about a fixed horizontal axis.

- (c) Lagrangian of a particle of mass m in spherical polar coordinate system with potential $V(r, \theta, \phi)$ is given by

$$L = \frac{1}{2}m(\dot{r}^2 + r^2\dot{\theta}^2 + r^2\sin^2\theta\dot{\phi}^2) - V(r, \theta, \phi)$$

obtain the Hamiltonian and Hamilton's canonical equation. 2+3=5

- (d) Define generalised momentum. What is cyclic coordinate? Show that generalised momentum corresponding to a cyclic coordinate is a constant of motion. 1+1+3=5

- (e) Given the Lagrangian

$$L = \frac{1}{2}M\dot{q}_1^2 + 2M\dot{q}_2^2 - K\left(\frac{5}{4}q_1^2 + 2q_2^2 - 2q_1q_2\right)$$

where M and K are positive constants. Calculate the potential energy matrix and kinetic energy matrix. 2½+2½=5

- (f) In the laboratory one particle A has velocity $V_A = +2.0 \times 10^8 \text{ m/sec}$, another particle B has velocity $V_B = -2.0 \times 10^8 \text{ m/sec}$. Calculate the velocity of A relative to B .

If the particle A is a photon, calculate the velocity of the photon relative to B . Is the result consistent with special relativity? 2+2+1=5

- (g) Energy E and momentum P of a particle of rest mass m_0 is given by $E = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$

and $P = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}}$ respectively. Find a

relation between E , P and m_0 . If K is the kinetic energy of the particle show

that $P = \sqrt{\frac{K^2}{c^2} + 2m_0 K}$. 2½+2½=5

- (h) A body of rest mass m_0 and velocity $v = 0.6c$ collides with another similar body at rest. After the collision the two bodies coalesce to form a composite body. Calculate the rest mass and velocity of the composite body so formed. 2½+2½=5

4. Answer **any two** questions : 10×2=20

- (a) State D'Alembert's principle and obtain Lagrange's equation for a holonomic conservative system. What is Lagrangian? 2+7+1=10

(b) Set up the Lagrangian and the Hamiltonian for a simple pendulum. Use Hamilton's canonical equations to obtain an equation describing its motion. 2+2+6=10

(c) Obtain the formula describing variation of mass with velocity. What is rest mass? 8+2=10

(d) A light pulse is emitted at the origin of a frame of reference S' at time $t' = 0$. Its distance from the origin after time t' is given by $x'^2 = c^2 t'^2$. Use Lorentz transformation to transform this equation to an equation in x and t and show that $x^2 = c^2 t^2$.

Discuss the implications of this result.

Show that if l_0^3 is the volume of a cube

at rest then $l_0^3 \sqrt{1 - v^2/c^2}$ is the volume

viewed from a reference frame moving in a direction parallel to an edge of the cube with velocity v . 5+2+3=10

(e) Describe stable equilibrium and unstable equilibrium of a system with the help of potential energy curve.

Lagrangian of a system with two degrees of freedom is

$$L = \frac{m}{2} (\dot{x}^2 + \dot{y}^2) - \frac{1}{2K} (x^2 + y^2) + \alpha xy$$

where $\alpha > 0$.

Determine the eigenfrequencies of the system. 5+5=10

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1 (Sem-4/FYUGP) PHY 42 MJ

2026

PHYSICS

(Major)

Paper : PHY4400204MJ

(Quantum Mechanics-I)

Full Marks : 45

Time : 2 hours

*The figures in the margin indicate
full marks for the questions.*

1. Give very short answers the following :

1×5=5

- (a) Write down the dimension of Planck's constant.
- (b) Name an experiment that suggests wave nature of radiation.
- (c) Write down Schrödinger equation for a free particle.
- (d) What is Hilbert space?
- (e) What is a quantum dot?

2. Answer the following questions : *(any five)*

2×5=10

- (a) Write down *any one* limitation of classical mechanics in explaining photoelectric effect.
- (b) Find the ratio of the de-Broglie wavelength to the Compton wavelength of a particle.

(c) Is it possible to simultaneously specify the kinetic energy and linear momentum of a mechanical system? Justify your answer.

(d) A nucleon is confined to a nucleus of radius $5 \times 10^{-15} \text{ m}$. Calculate the minimum uncertainty in the momentum of the nucleon.

(e) State the physical significance of the wave function $\psi(x, t)$?

(f) What is a wave packet? How it affect the localization of the particle?

(g) Distinguish between phase velocity and group velocity.

(h) Justify that tunnelling is a quantum mechanical phenomenon.

(i) Show that eigenvalues corresponding to Hermitian operators are real.

- (j) Distinguish between a classical and a quantum harmonic oscillator.

3. Answer **any four** questions : $5 \times 4 = 20$

- (a) Calculate the minimum energy required by a photon to transfer half of its energy to an electron at rest.

- (b) Find the condition for two wave functions to be orthonormal. Find the probability current density for the wave function

$$\psi = \frac{e^{ikr}}{r} \quad 2\frac{1}{2} + 2\frac{1}{2} = 5$$

- (c) What do you mean by expectation value of a dynamical variable? Find the expectation value of momentum for a particle described by the wavefunction

$$\psi(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{\pi x}{L}\right) \text{ for } 0 < |x| < L$$

$$= 0 \text{ elsewhere} \quad 2 + 3 = 5$$

- (d) Show that if $\psi_1(\vec{r})$ and $\psi_2(\vec{r})$ are two independent solutions of the Schrödinger equation then

$\psi(\vec{r}) = a_1\psi_1(\vec{r}) + a_2\psi_2(\vec{r})$ is also a solution of Schrödinger equation.

- (e) Write the significance of energy time uncertainty principle. Discuss how we can estimate the range of interaction for fundamental force using energy time uncertainty relation and virtual particles.

- (f) Explain *two* slit experiments with electron and discuss its significance.

- (g) Discuss the properties of a Gaussian wave packet.

- (h) Write down the radial wave function for 1s state of hydrogen atom. Also, compare the probabilities of a 1s electron in the hydrogen atom being at a distance a_0 from the nucleus than at a distance $a_0/2$. $1 + 4 = 5$

4. Answer the following questions : **(any one)**

10×1=10

- (a) What was the main discrepancy of Rayleigh-Jeans formula for black body radiation? Derive Planck's law and discuss how the discrepancy was solved.

2+6+2=10

- (b) A particle is in an infinite potential well

$$v(x) = \begin{cases} 0, & 0 < x < a \\ \infty, & \text{elsewhere} \end{cases}$$

Find out the energy eigenvalues and eigenfunctions. Also schematically show the wave functions and probability densities for first three states.

8+2=10

- (c) Show that average motion of a wave packet follows Newton's second law of motion. What is the significance of Ehrenfest's theorem.

- (d) (i) Explain the significance of the quantum numbers n , l and m . Can the principal quantum number of electron in hydrogen atom be zero.

3+1=4

- (ii) Show that the most probable distance of the electron from the nucleus in the ground state of hydrogen atom is equal to the Bohr's radius a_0 .

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1 (Sem-4/FYUGP) PHY 43 MJ

2026

PHYSICS

(Major)

Paper : PHY4400304MJ

(Analog Electronics)

Full Marks : 45

Time : 2 hours

*The figures in the margin indicate
full marks for the questions.*

1. Answer the following questions : $1 \times 5 = 5$

(a) In a PN junction, the region containing uncompensated acceptor and donor ions is called the :

- (A) Neutral region
- (B) Depletion region
- (C) Active region
- (D) Diffusion region

(Choose the correct option)

(b) State whether the following statement is True **or** False :

“Applying negative feedback to an amplifier increases its voltage gain while improving its stability.”

(c) Name the primary condition for self-sustained oscillations in an amplifier circuit.

(d) The _____ is the maximum rate of change of output voltage per unit time in case of Op-Amp.

(Fill-up the blank)

(e) In CRO, what type of waveform is generated by the time base circuit to move the electron beam horizontally?

2. Answer the following questions : *(any five)*
 $2 \times 5 = 10$

(a) Calculate the drift velocity of electrons in a semiconductor if the electron mobility is $1350 \text{ cm}^2/\text{V.s}$ and the applied electric field is 100 V/cm .

(b) Draw the circuit diagram of a voltage regulator using Zener diode.

(c) Mention *two* differences between *fixed bias* and *voltage divider bias* for transistor amplifiers.

(d) A transistor has a common-base current gain (α) of 0.98. Calculate its common-emitter current gain (β).

(e) What do you mean by the *active region* for a transistor amplifier?

(f) Why is a coupling capacitor used between the two stages of an RC-coupled amplifier?

(g) An amplifier has an open-loop voltage gain (A) of 1000. If negative feedback with a feedback fraction (β) of 0.04 is applied, calculate the gain with feedback (A_f).

- (h) Calculate the frequency of oscillation for an RC Phase Shift Oscillator if $R = 10k\Omega$ and $C = 0.01\mu F$.
- (i) Draw the basic circuit diagram for an inverting amplifier and write the formula for its closed-loop voltage gain.
- (j) Write *two* differences between Class B and Class C amplifiers.

3. Answer the following questions : **(any four)**

5×4=20

- (a) (i) Explain the concept of "Virtual Ground" in an Op-Amp. Why is it significant for circuit analysis?

2+1=3

- (ii) For a closed loop non-inverting amplifier, the resistors are $R_f = 47k\Omega$ and $R_1 = 4.7k\Omega$. If the output voltage is measured at 11V, what was the applied input voltage?

2

- (b) (i) Explain the "Summing Amplifier" configuration in inverting mode.

2

- (ii) A summing amplifier has three input resistors : $R_1 = 10k\Omega$, $R_2 = 20k\Omega$, and $R_3 = 50k\Omega$. The feedback resistor is $R_f = 100k\Omega$. If $V_1 = 1V$, $V_2 = -2V$ and $V_3 = 3V$, find the output voltage.

3

- (c) (i) What is the purpose of the Time Base Generator in a CRO? What happens to the display if the time base is turned off?

2

- (ii) The horizontal "Time/Div" control is set to $2ms/div$. One complete cycle of a signal occupies 2.5 horizontal divisions. Calculate the period (T) and the frequency (f) of the signal.

3

- (d) Explain how a CRO is used for the measurement of Phase difference using Lissajous Pattern.
- (e) Draw the circuit diagram of a RC Phase shift oscillator. Derive the expression for its frequency of Oscillation.
- (f) Explain how negative feedback improves the "Gain Stability" of an amplifier.

(g) A negative feedback of $B=0.002$ is applied to an amplifier of gain 1000. Calculate the percentage of change in overall gain of the feedback amplifier if the internal amplifier is subjected to gain reduction of 15%.

(h) In an RC coupled amplifier, the coupling capacitor C_C is $0.1\mu F$ and the input resistance of the second stage R_{in2} is $2k\Omega$. The output resistance of the first stage R_{o2} is $10k\Omega$.

(a) Calculate the lower (3-dB) cutoff frequency (f_L) of the coupling network.

(b) If the frequency of the input signal is reduced to $50Hz$, explain qualitatively what happens to the voltage gain.

3+2=5

4. Answer the following questions : **(any one)**

10

(a) (i) Define a step junction and explain the distribution of charge carriers across its depletion region.

1+2=3

(ii) Deduce an expression for barrier width of a PN junction. 7

(b) (i) Draw the circuit diagram of a Full-wave Bridge Rectifier and explain its working during both positive and negative half-cycles of the AC input. 2+3=5

(ii) A bridge rectifier uses four identical diodes, each having a forward resistance r_f of $10k\Omega$. The secondary voltage of the transformer is $20V$ (rms) and the load resistance (R_L) is 400Ω . Calculate the DC output voltage and the Rectification Efficiency. 5

(c) (i) Explain the concept of DC Load Line in transistor characteristics. How is it used to find the Q-point? 2+1=3

(ii) Explain the "Load Line" shift that occurs if the load resistance is changed while the supply voltage remains constant. 2

- (iii) Find the collector current (I_C) and collector-emitter voltage (V_{CE}) for a circuit where $V_{CC} = 12V$, $R_C = 2k\Omega$, and the transistor is at cutoff. 2+3=5
- (d) (i) Represent a transistor as a 2-port network and define the four h -parameters (h_{ie} , h_{re} , h_{fe} , h_{oe}) for a Common Emitter configuration. 3
- (ii) Draw the h -parameter equivalent circuit of a single-stage CE amplifier. 2
- (iii) For a CE amplifier, the h -parameters are $h_{ie} = 1.1k\Omega$, $h_{fe} = 50$, $h_{re} = 2.5 \times 10^{-4}$ and $h_{oe} = 25\mu A/V$. If the load resistance (R_L) is $2k\Omega$, calculate the Current Gain and Input Impedance. 5
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1 (Sem-4/FYUGP) PHY 44 MJ

2026

PHYSICS

(Major)

Paper : PHY4400404MJ

(Mathematical Physics)

Full Marks : 45

Time : 2 hours

*The figures in the margin indicate
full marks for the questions.*

1. Answer the following questions : $1 \times 5 = 5$

(a) Write the two dimensional wave equation of a vibrating membrane.

(b) Find the period of the function

$$f(x) = 2\sin x + 4\cos x.$$

(c) State Residue theorem.

(d) What do you mean by contraction of tensors ?

(e) Write the expression for mean and variance of Poisson distribution.

2. Answer **any five** of the following questions :
 $2 \times 5 = 10$

(a) Write the orthogonality condition of sine and cosine functions.

(b) Check whether the complex function $f(z) = |z|$ is analytic or not.

(c) Evaluate $\int_C (z - z^2) dz$, where C is upper half of the circle $|z| = 1$.

(d) State the Dirichlet conditions for the existence of a Fourier series.

(e) Write the law of transformation for the tensor

(i) A_{qr}^p

(ii) B_{ijk}^{mn}

(f) Prove that the contraction of the tensor A_q^p is a scalar or invariant.

(g) What is singularity of an analytic function? Find the singularity of the function $f(z) = \frac{z+3}{(z-1)(z-2)}$ and write

the type of the singularity of this function.

(h) Expand the function $f(x) = x$ for $0 < x < 2\pi$ in Fourier series.

(i) Express Laplace's equation in two dimensional Cartesian form and write its solution for positive separation constant.

- (j) A coin is tossed thrice. A success is getting 1 or 6 on a toss. Find the mean and variance of the number of success.

3. Answer **any four** of the following questions :
5×4=20

- (a) Solve the wave equation $\frac{\partial^2 y}{\partial t^2} = c^2 \frac{\partial^2 y}{\partial x^2}$

under the following conditions :

$$y(0, t) = 0, y(l, t) = 0, y(x, 0) = a \sin \frac{\pi x}{l}$$

$$\text{and } \frac{\partial y(x, 0)}{\partial t} = 0.$$

- (b) A function is defined as

$$f(x) = \begin{cases} 0 & \text{for } -\pi < x < 0 \\ h & \text{for } 0 \leq x < \pi \end{cases}$$

is termed as a square-wave function. Obtain the Fourier series expansion.

- (c) State and prove the Cauchy's integral formula for complex integration.

- (d) Find the value of the integral

$$\int_0^{1+i} (x - y - ix^2) dz \text{ along real axis from}$$

$z = 0$ to $z = 1$ and then along a line parallel to imaginary axis from $z = 1$ to $z = 1 + i$.

- (e) What is Kronecker delta? Show that Kronecker delta is a mixed tensor of rank 2. 2+3=5

- (f) Using residue theorem evaluate the integral $\int_C \frac{4-3z}{z(z-1)(z-2)} dz$ where C

is the circle $|z| = \frac{3}{2}$.

- (g) Using the method of separation of variables, solve $\frac{\partial u}{\partial x} = \frac{\partial u}{\partial y} + u$, where

$$u(x, 0) = 3e^{-4x}.$$

- (h) Express the Fourier series in complex form.

4. Answer **any one** of the following questions :

$$10 \times 1 = 10$$

(a) Find the Fourier series expansion of

$$f(x) = \begin{cases} -\pi, & \text{for } -\pi < x < 0 \\ x, & \text{for } 0 < x < \pi \end{cases}$$

$$\text{Also show that } \frac{\pi^2}{8} = \frac{1}{1^2} + \frac{1}{3^2} + \frac{1}{5^2} + \dots$$

$$7 + 3 = 10$$

(b) (i) Expand the following function in Taylor series :

$$f(z) = \frac{1}{z+1}, \text{ about } z = 1 \quad 5$$

$$(ii) \text{ Show that } \int_0^{\infty} \frac{dx}{1+x^2} = \frac{\pi}{2}$$

(using residue theorem) 5

(c) (i) What are symmetric and antisymmetric tensors ? Prove that any second rank tensor can be written as a sum of symmetric and antisymmetric tensor. 2+4=6

(ii) What is Levi-Civita tensor ? Prove that $\delta_{ij} \epsilon_{ijk} = 0$. 2+2=4

(d) (i) What is analytic function ? Deduce Cauchy-Riemann equation as a necessary condition for a complex function to be analytic. 1+6=7

(ii) Expand $f(z) = \frac{e^z}{(z-1)^2}$ in Laurent's series about $z = 1$. 3